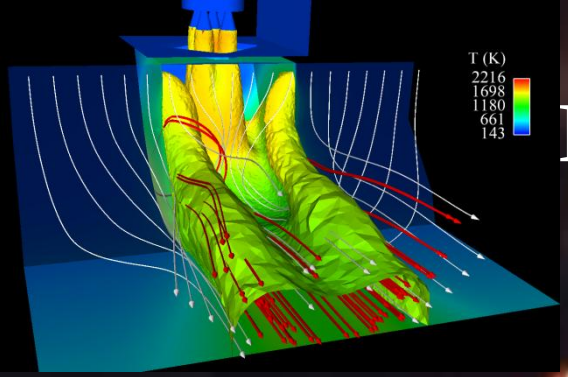


Propulsion Across NASA

AIAA NO Section Dinner Meeting

September 14, 2010

David Coote, Chief
Engineering Design & Analysis Division, ETD, SSC

Outline

- **Introductory Remarks**
- **Propulsion NASA Mission Readiness**
  - Aeronautics Research Mission
  - Science Mission
  - Space Operation Mission
  - Exploration Systems Mission
- **Propulsion Roadmap**
- **Review of Center Capabilities**
- **Current Challenges**

- **This presentation is a compilation of a several presentations**
  - NASA Joint Engineering Management Board and Safety and Mission Assurance Directors' Meeting Brief – Robert Garcia & Mike Meyers (Dec 2008)
  - NASA's Rocket Propulsion Test Management Board
  - NESC Propulsion Technical Discipline Team meeting reviewing respective Center's propulsion activities (July 2010)
  - Plus, general info from NASA's Rocket Propulsion Test program

Introductory Remarks

- **Propulsion expertise has recently been in high demand across all of the NASA missions**
  - Constellation in particular placed a large burden and opportunity on NASA's propulsion skills and capability
  - Its replacement program will have equal or greater propulsion systems development needs

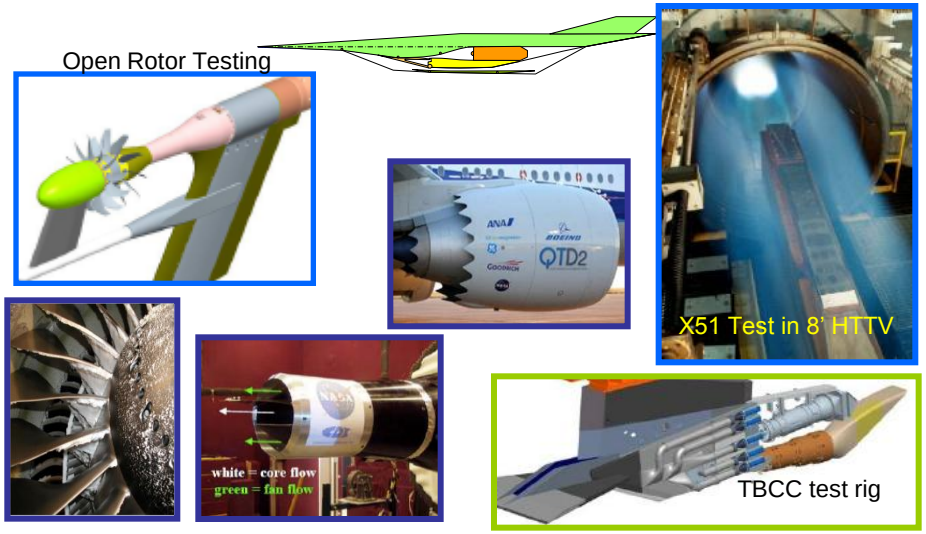
- **NASA's missions require a very broad breath of varying propulsion configurations.**
  - Air-breathing (subsonic, supersonic, and hypersonic)
  - Chemical propulsion (liquid, solid, cryogenic, hypergolic)
  - Electric propulsion (battery, solar, nuclear, …)
  - Within each configuration there are unique subsystems and models of operation

- **While there are overarching common skills, each major branch of the propulsion tree tends to have unique skills and infrastructure needs.**
  - Physics, materials, internal and external environments, time of operations, etc., can lead to unique design, development, and operational capability needs.

Aeronautics Research Mission

Requirements

- **Research into techniques for:**
  - Improved fuel efficiency
  - Noise and emissions reduction
  - Overland travel for supersonic/hypersonic aircraft
  - RBCC/TBCC for launch systems
  - Scramjet for atmospheric travel
- **Collaboration with other government agencies and industry**



Challenges

- **Limited Procurement funding**
- **Loss of competency-supporting WYEs**
  - Developing creative partnerships with industry to enable TRL maturation
- **Support for test infrastructure and operations**

Resources

Expertise

Y	Design	↓
G	Analysis	↓
Y	Test	↓

Modeling

G	System	—
Y	High Fidelity	↓

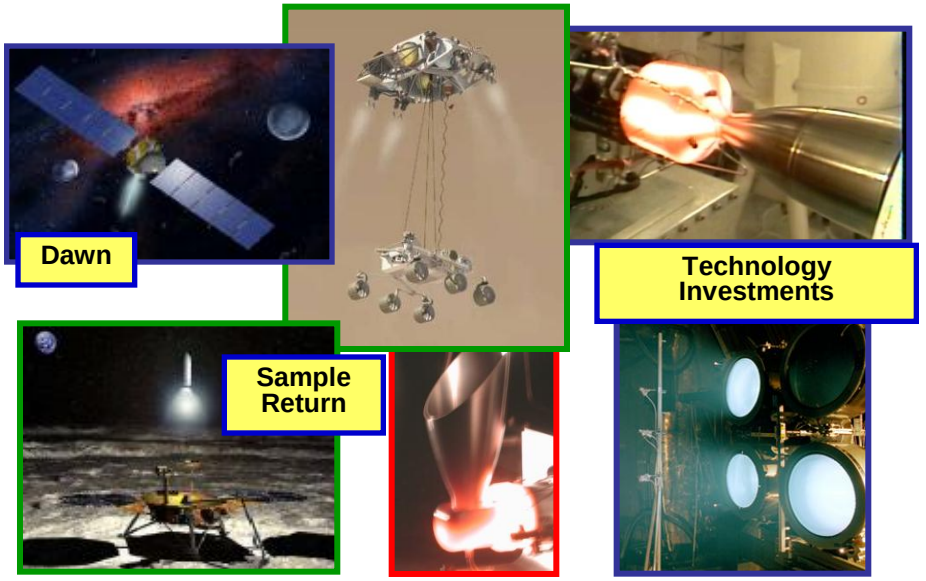
Facilities

Y	Engineering Evaluation	—
Y	System Test	—

Science Mission

Requirements

- **Science mission propulsion generally driven by planetary missions**
  - Reduce transit time
  - Increase scientific payload capability
  - Enable sample return missions
  - Mission cost reduction
- **Support of missions from pre-Phase A through operations**



Challenges

- **Identification of long term technology needs**
- **Declining technology advancement budget**
- **Transition to flight**
- **Accurate cost projection**
- **Competency maintenance for unique NASA mission requirements**
- **Changing mission priorities**

Resources

Expertise

Y	Design	—
G	Analysis	—
G	Test	—

Modeling

G	System	—
Y	High Fidelity	↓

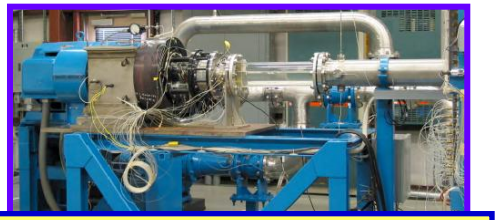
Facilities

G	Engineering Evaluation	—
G	System Test	—

Space Operations Mission

Requirements

- **Shuttle propulsion operations**
  - Continued safety improvements
  - Hardware acceptance
  - Pre-flight performance predictions
  - Launch operations support
  - Post flight performance assessment
  - Trending analysis



Infrastructure Investments

Challenges

- **Graceful/safe end to Shuttle operations and transition to Constellation**
- **Manufacturing base obsolescence**
- **Support for infrastructure, skills, capabilities post shuttle**

Resources

Expertise

G	Design	↓
G	Analysis	—
G	Test	↓

Modeling

G	System	—
G	High Fidelity	↑

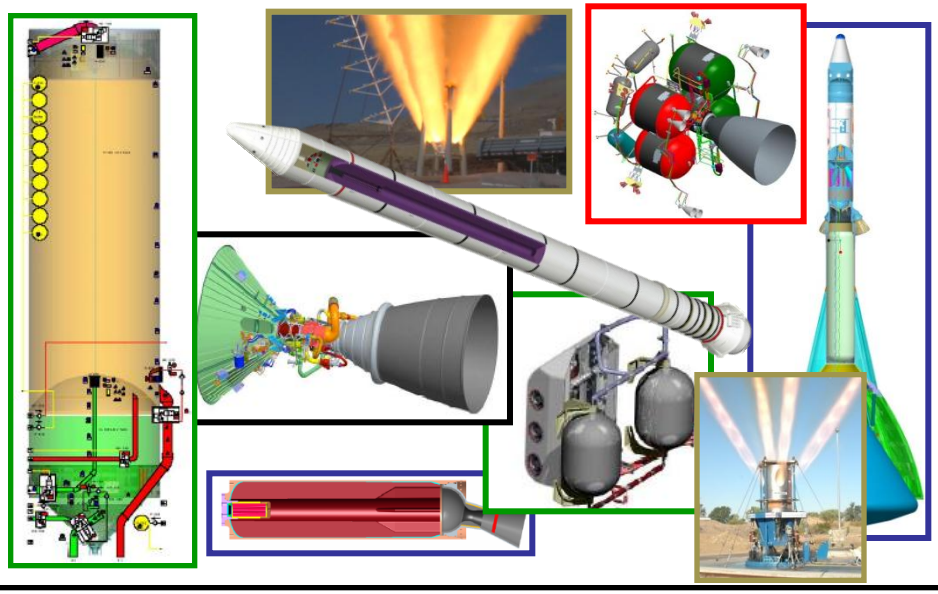
Facilities

G	Engineering Evaluation	—
G	System Test	↓

Exploration System Mission

Requirements

- **Independent assessments for Industry led design and design activities**
  - Orion, J-2X, RSRMV
  - Requirements definition, development and qualification plans
  - Selected independent analysis and testing
- **Design and initial development**
  - Upper stage MPS, ullage motors, roll-control, RCS
- **Definition and technology development for Ares V and Altair**



Challenges

- **Rapid "staffing" to catch up with project needs**
  - Head-counts addressed, experience a work in progress
- **Complex organizational relationships**
  - Communication, standards/expectations for "in-house" workforce support
- **Lack of standard for propulsion qualification requirements**
  - Budget/schedule pressures leading to hardware lean projects.
  - Greater reliance on experience, similarity, analysis

Resources

Expertise

Y	Design	↑
G	Analysis	—
G	Test	—

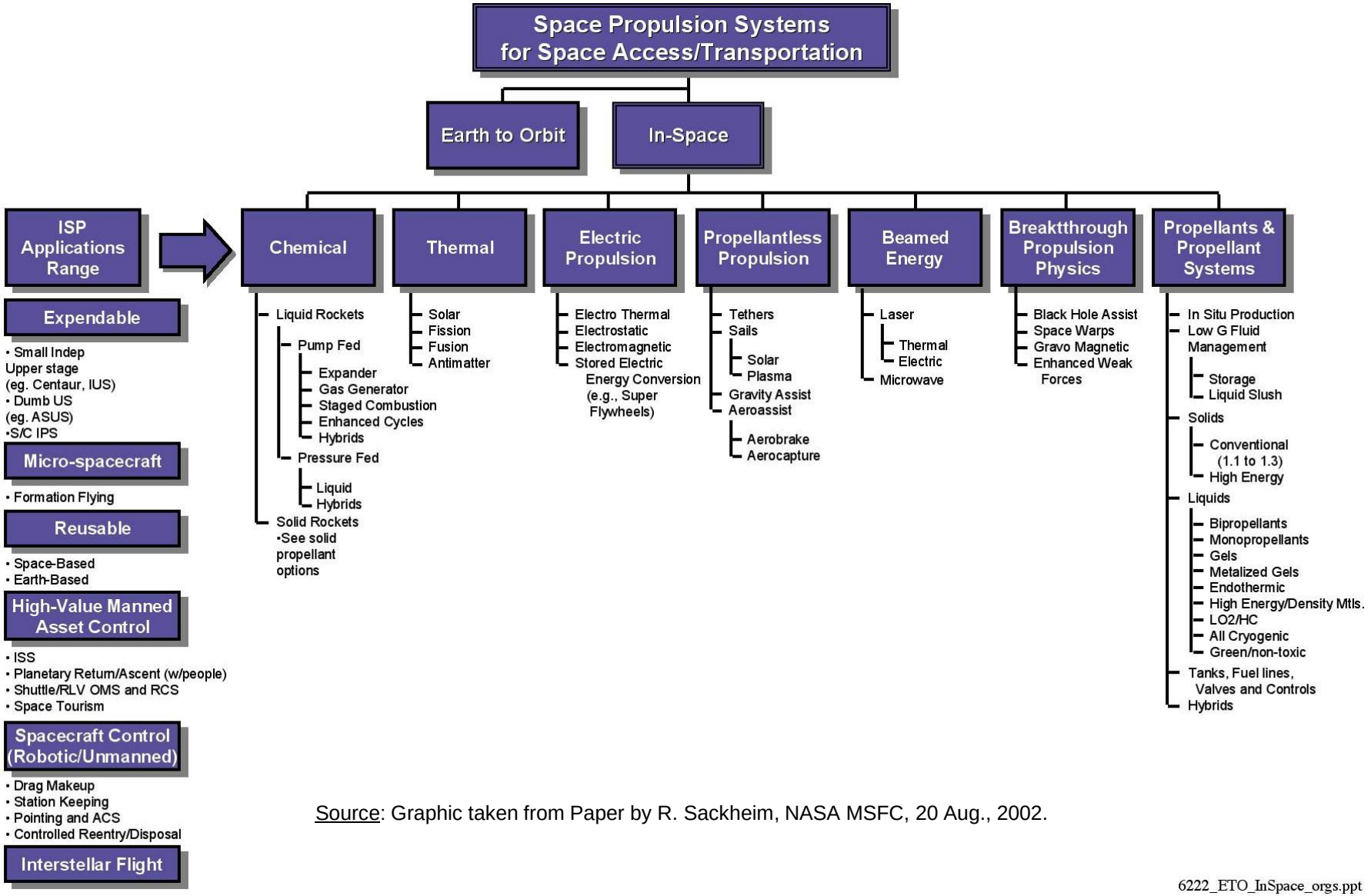
Modeling

G	System	↑
Y	High Fidelity	—

Facilities

G	Engineering Evaluation	—
Y	System Test	↑

Example of In-Space Propulsion "Tree"



Source: Graphic taken from Paper by R. Sackheim, NASA MSFC, 20 Aug., 2002.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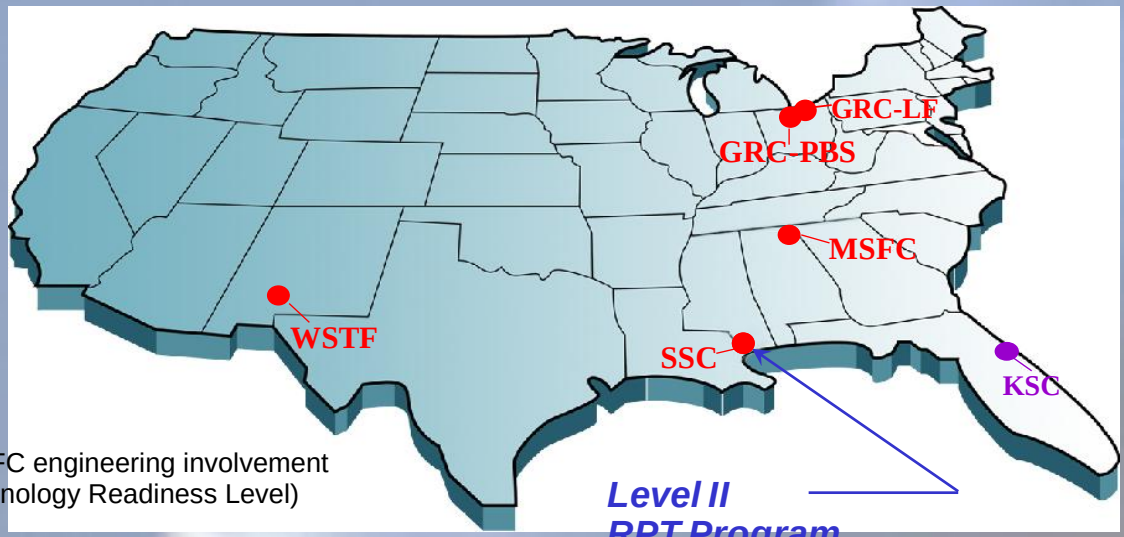
NASA's Rocket Propulsion Test Program



Marshall Space Flight Center:
Primary NASA site for:
- MSFC designed/developed component level test articles
- Technology development test articles with substantial MSFC engineering involvement
- Propulsion component research and technology (low Technology Readiness Level)
- Cryo structural test articles (tanks, ducts, etc.)

Alternate NASA site for:
- Non-hypergolic, ambient testing

White Sands Test Facility:
Primary NASA site for:
- Altitude testing of small/medium test articles up to 15k lb thrust, excluding LOX/LH2
- All hypergolic testing

Plum Brook Station:
Primary NASA site for:
- Altitude testing of medium/large test articles in the 1k to 400k lb thrust range, excluding hypergolics; includes all LOX/LH2 testing

Alternate NASA site for:
- Cryo structural test articles (tanks, ducts, etc.)

Stennis Space Center:
Primary NASA site for:
- Non-hypergolic, ambient/low-altitude testing
- Excludes other centers' baseline test assignments

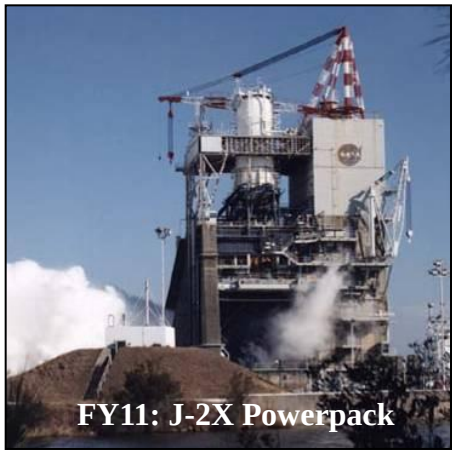
SSC

Test Complex Visual Perspective

Manage, develop, and operate SSC Rocket Propulsion Test (RPT) capabilities and facilities

- Provide sustaining engineering expertise and operations experience to ensure the safe operation and continued sustainment of one-of-a-kind national test facilities valued at over $2 billion
- Provide technical oversight of rocket engine propulsion test programs such as the RS68, J-2X & AJ26

SSC Test Stands

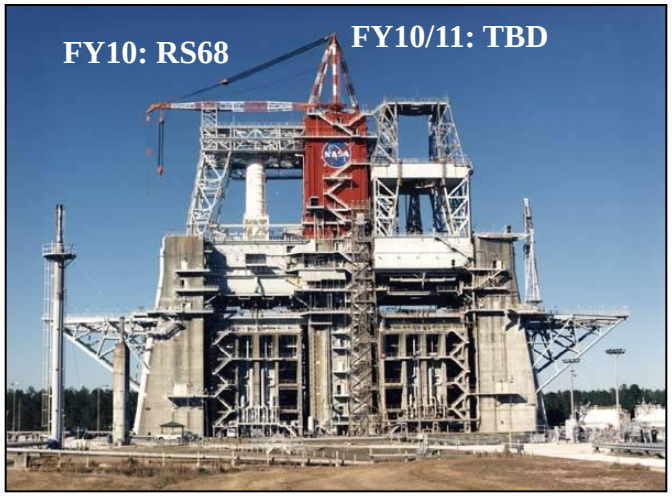


A-1

A-2

E-1

E-2



B-1 B-2

E-3

Engine & Stage Test Stands (Apollo heritage)

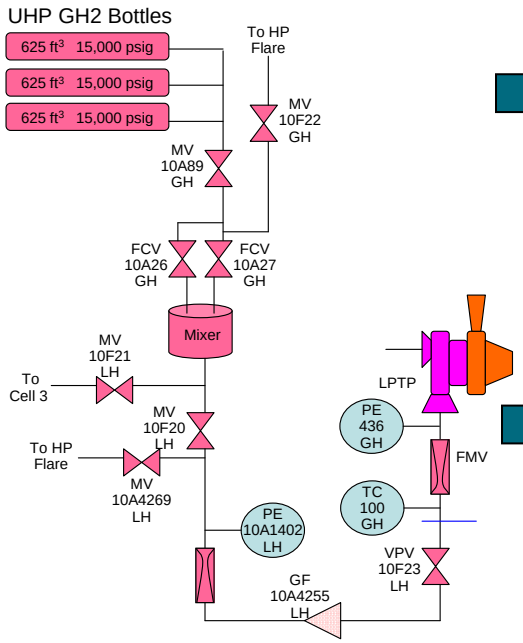
Engine & Component Test Stands

Integrated Facility Simulation and Analysis

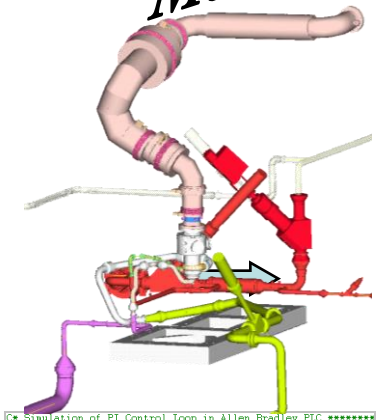
- Analytic Tools Available for Test Facility/Project Modeling & Analysis
- Comprehensive Propellant System Thermodynamic Modeling & Test Simulation

Integrated Performance Modeling Capabilities Substantially Improves Understanding & Knowledge of Test Systems Performance that has Translated to Efficient Test Facility Design, Activation & Test Operations

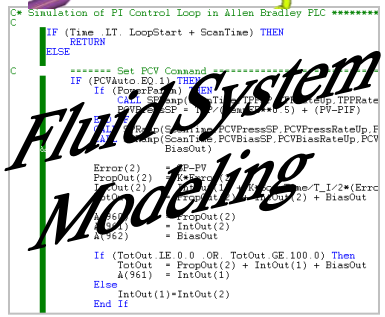
System Design



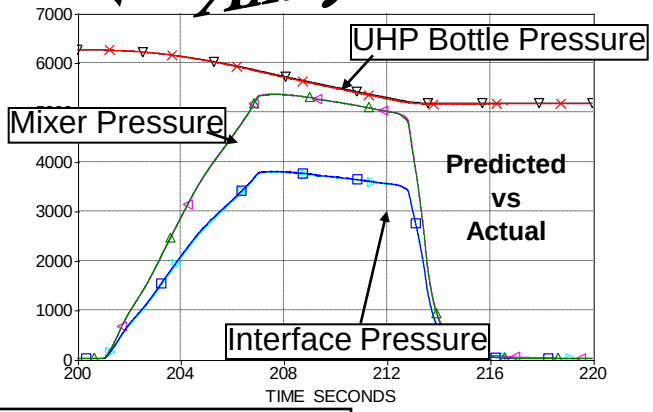
Modeling

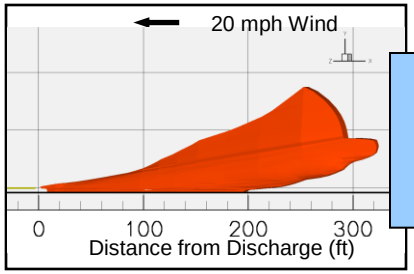


Fluid System Modeling



Test and Data Analysis





Advanced Capabilities in CFD Modeling & Analysis

Rocket Propulsion Test Program

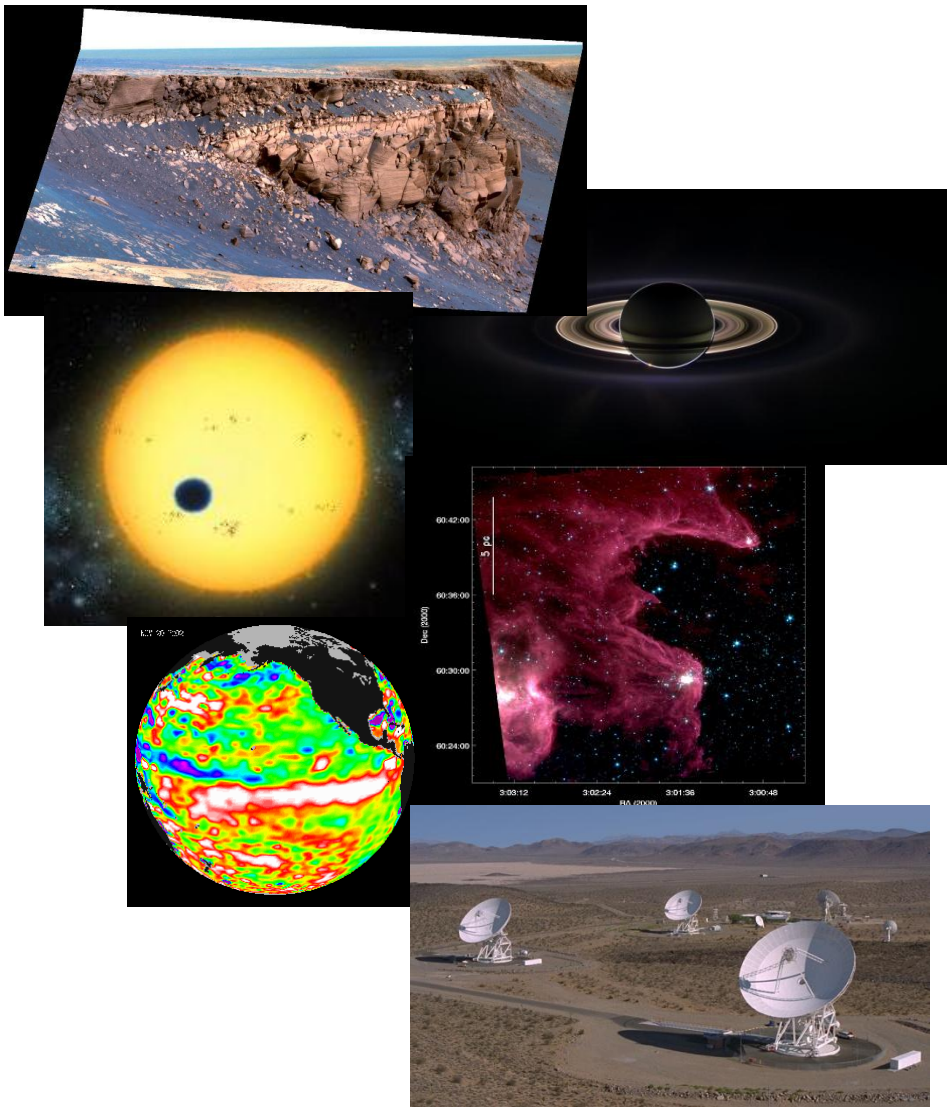
White Sands Test Facility

- Propulsion Test Office
  - Nine Test Stands
    - *Altitude Simulation Systems*
    - *Pyrotechnic Systems Development*
    - *Propellant and Fluids Storage and Distribution Systems*
- Test Support Organizations
  - Precision Cleaning, Component Services, Fabricaton, Calibration Labs, Photo/Video/Documentation
  - Chemistry/Metallurgical lab
- Laboratories Office
  - Aerospace Fluids, Materials, and Component Testing
  - Hypervelocity Impact Testing

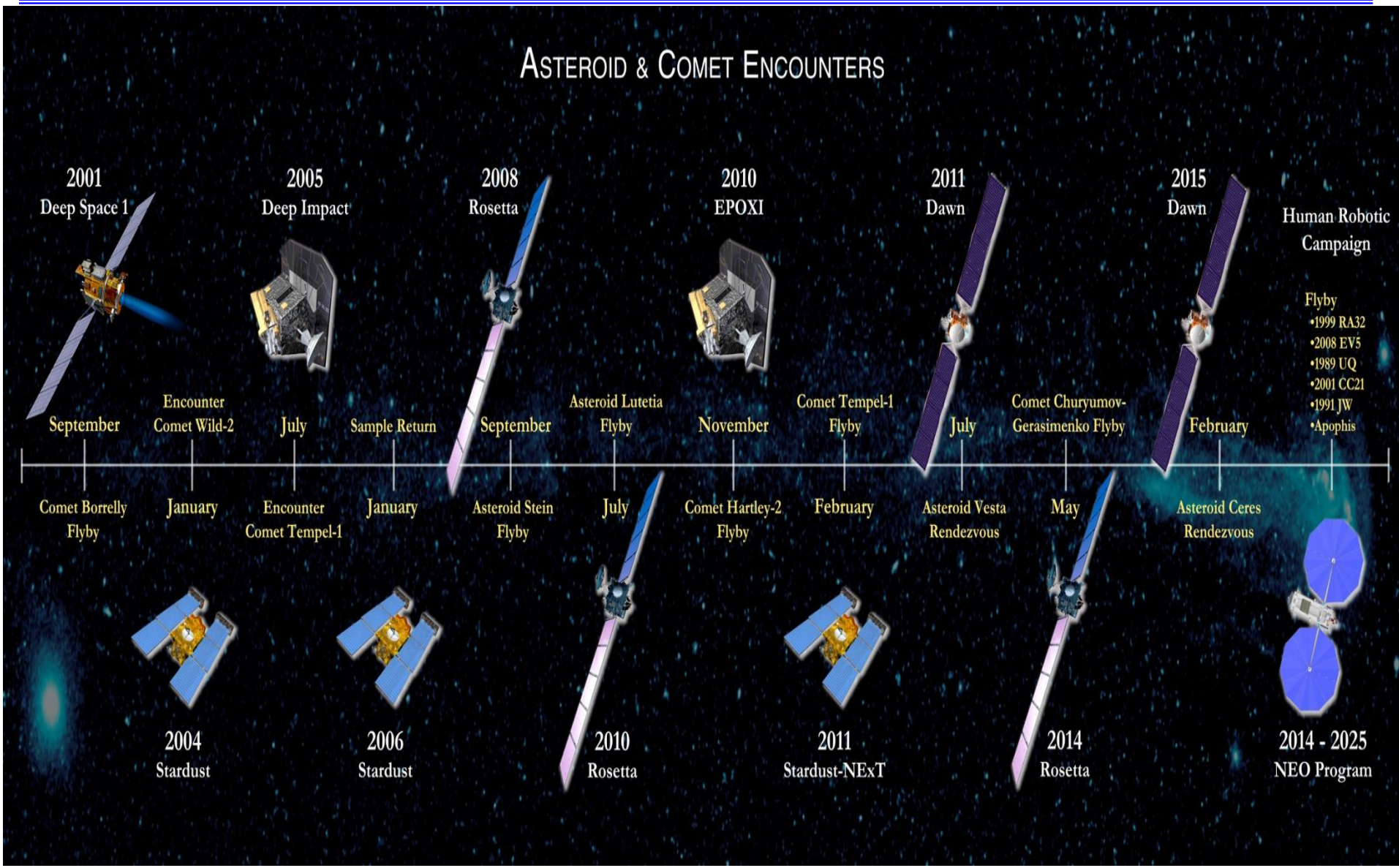
Jet Propulsion Lab

JPL's Mission for NASA is *Robotic* Space Exploration

- Mars
- Solar system
- Exoplanets
- Astrophysics
- Earth Science
- Interplanetary network



Recent & Planned Asteroid and Comet Mission History



Propulsion at JPL

- **Organization**
  - Two propulsion groups at JPL
    - Electric Propulsion and Chemical Propulsion

- **Goals are performance and system improvements for Missions**
  - Technology maturation and implementation
  - System Analysis
  - Test Facilities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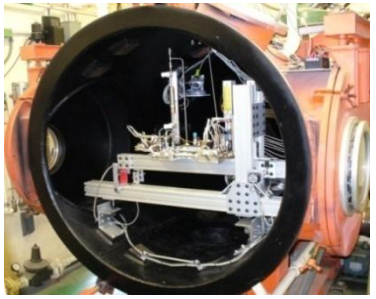
JPL: Low Thrust Chemical Test Facility

❖ ***The JPL Chemical Thrust Test Facility has state-of-the-art thrust and impulse measurement systems.***

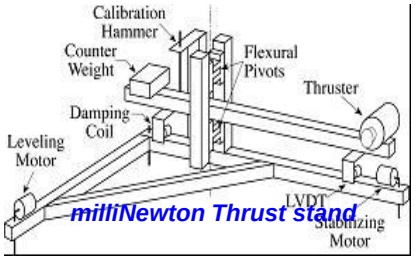


Thrust Stand Infrastructure

- Capability to test a range of thrusters: 22 N – to sub-milliNewton (< .001N)
- Ability to measure individual impulse-bits to < 50 microNewton-seconds.
- Maintain vacuum levels to < 10 millitorr during test.

❖***Near term plans for testing include:***

- ***22 N thrusters using AFM-315e green propellant***
- ***R&D Arcjet thrusters for industry***
- ***Flight qualification of a 4.5 N hydrazine thruster***



milliNewton Thrust stand

Johnson Space Center

AREAS OF EXPERTISE

PROPULSION

-Cold/warm gas, Earth storables, Cryogenics
-Mono-propellant & Bi-propellant thrusters
-Attitude control systems
-Orbit adjust systems
-Propellant Management & transfer

POWER SYSTEMS

-Fuel Cells
-Primary & secondary batteries
-Chargers
-Electrical power distribution & control

PYROTECHNICS

-Initiators and Detonators
-Linear explosives
-Cartridge Actuated Devices
-Crew escape systems

In-Situ Resource Utilization (ISRU)

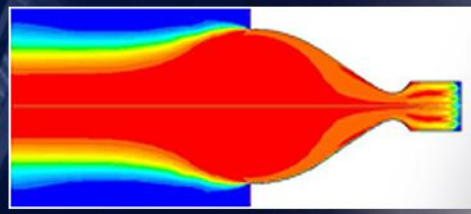
-Lunar processing to extract oxygen
-Processing reactors
-Water electrolysis
-Gas/Liquid separation & cleaning

Johnson Space Center

PROPULSION OVERVIEW

JSC's Core Competencies cover the range of skills required for development & operation of Spacecraft Propulsion Systems

- Cold Gas, Earth-Storables, & Cryogenics
- Concept, Mission, & Architecture Trade Studies
- Cryogenic Fluid Management
- System Design & Analysis
- System & Vehicle Integration
- Component Design Expertise
- System Certification & Human Rating
- Flight Operations Support
- Demonstrated Rapid Response for Anomaly Resolution

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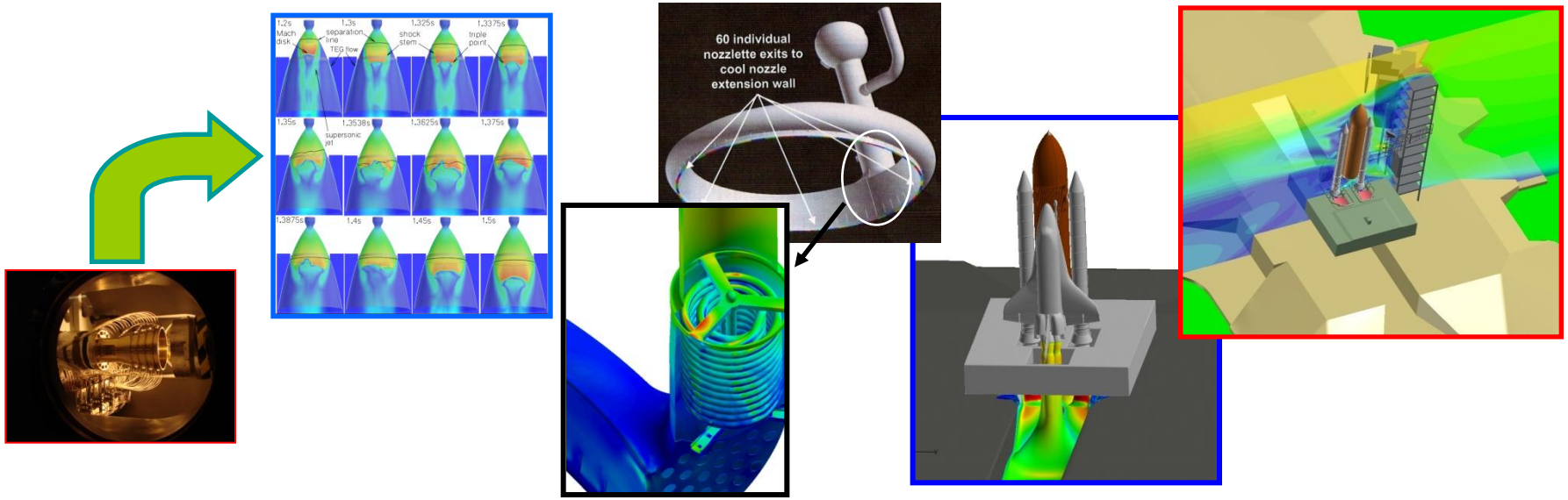
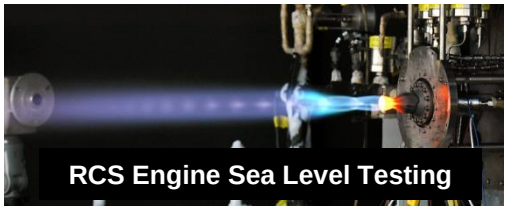
Top Propulsion Challenges

- **Funding for continued improvement in high fidelity simulations and the infrastructure that supports it.**
  - Projects continue to increase reliance on simulation and high fidelity analyses to reduce design risk and performance design verification
  - Propulsion activities are one of the largest users of agency computing resources
    - Time accurate, multi-species, reacting, multi-phase, multi-disciplinary – causes of failure
    - Constellation greatly benefitting from past investments but current support weak
  - The demand is expect to increase sharply over the next 2-7 years
    - Simultaneous Ares 1, Ares V, and Altair propulsion system design, development, and early flight operations



Top Propulsion Challenges (continued)

- **Maintaining NASA mission unique expertise in tight budget situation**
  - Some propulsion expertise may only be needed once or twice a decade to support
- **Development of and insertion of propulsion technology into flight missions**
  - Competitive mission selection process in science and schedules in exploration generally present disincentive for using new propulsion technology
    - Long life demonstration of EP in-space (NEXT)


RCS Engine Sea Level Testing


Feed-system Integrated Testing

Summary (from Introductory Remarks)

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Thank You